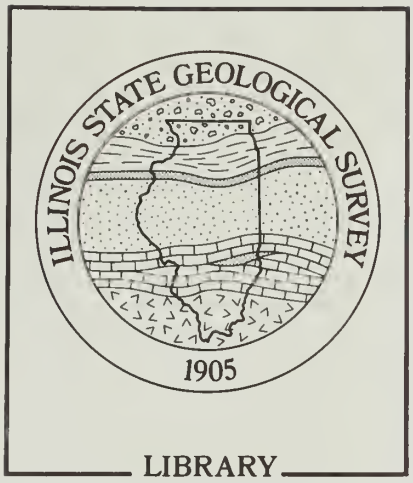
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Illinois State Geological Survey addresses challenges for a healthy economy and a healthy environment

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Illinois State Geological Survey addresses challenges for a healthy economy and a healthy environment

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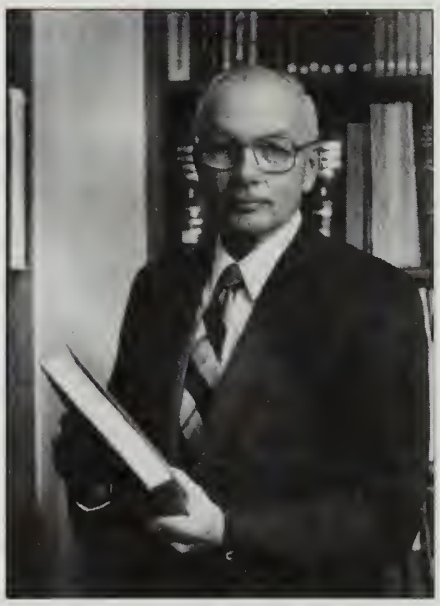
From the Chief

Research at the Illinois State Geological Survey (ISGS), a division of the Department of Energy and Natural Resources (ENR), strengthens the state's economy by encouraging sound exploration, logical development, and intelligent use of mineral resources. At the same time, the Survey's efforts are directed toward providing geological information vital for developing judicious environmental policies to protect and enhance the health, safety and well being of Illinois' citizens.

Earth-related sciences will continue to play an evermore important role in resolving the multitude of complex environmental- and resource-related issues facing the state...nation...and world. This annual report, prepared especially for the general public, presents three major issues and the Geological Survey's research and service programs and projects which respond to those concerns. The period covered is Fiscal Year 1991, extending from July 1, 1990, to June 30, 1991.

At issue is the ability to provide **an adequate supply of domestic petroleum for transportation fuels,** one of the most serious short- and long-term energy problems for the country today. Of major concern are the ongoing developments in the oil industry that have had a nationwide impact on research efforts, domestic oil production, and economic development in oil-producing states. Imports for the past couple of years have approximated 50 percent of the nation's supply of crude oil and petroleum products, placing the United States in a steadily worsening economic position, while increasing concerns for security of supplies.

While Illinois' oil production has decreased sharply from 30 million to under 20 million barrels of oil a year, large quantities



of discovered oil remain trapped within already discovered reservoirs. Only about 35 percent of the oil-in-place has been produced, leaving 1.4 billion barrels of oil as by-passed mobile oil and another 4.5 billion barrels as residual oil. A major effort is under way at the ISGS to find economic ways to get more of this oil out of the ground. Our scientists are determining which methods of improved recovery work best for the wide range of conditions existing in Illinois' oil fields. A segment of this report focuses on this research and the means by which the Survey is transferring the results and knowledge gained to the oil industry in this state....

At issue is **protecting Illinois' groundwater from contamination.** The ISGS is very actively involved in meeting mandates of the Illinois Groundwater Protection Act by conducting pertinent map-

ping, assessments, monitoring, and technical assistance programs in support of the protection and preservation of groundwater's quality as well as the management of this vulnerable resource. Approximately two-thirds of the state's population depend on groundwater as a source of supply. In a number of cooperative efforts highlighted in this report, the Geological Survey's scientists have been working to evaluate the impact of agricultural chemicals (pesticides and nitrates) on groundwater, particularly in rural areas where they are most intensively used....

At issue is the **need for** but absence of **detailed geological mapping** for about 97 percent of Illinois to address environmental- and resource-related issues that face the state at regional and local levels. Detailed geologic maps and other studies of regions, counties or smaller units provide state and regional planners, county boards, public health departments and citizens with information about the Earth's surface and the materials that lie beneath it—information required to sustain economic development and protect the environment.

Almost every area of the state faces problems with waste disposal, groundwater protection, and the environmental effects of normal human activities. Detailed geological information is required to ensure maximum protection from possible contamination of our supplies of groundwater and surface water; to ensure that major highways, railroads, factories, schools and other facilities are constructed on sites that provide adequate support for foundations and are free of threats from flooding, landslides, and other man-caused and natural earth hazards; and to guide officials in deciding the direction of future economic development.

Although much is known about the geology of Illinois at statewide and regional scales, "detailed" geological maps are available for only a few limited areas. Thus, a program of detailed geological mapping is required to provide the necessary geologic information to cover important state and regional concerns. A segment of this report is devoted to the mapping needs of the state and the nation and the manner in which a program of this magnitude is attainable.

While this annual report highlights only three issues and respective ongoing research and service programs at the ISGS, the scope of the Survey's efforts is far wider, affecting jobs and economic growth, environmental protection, energy security, access to minerals and clean water, appropriate use of land, proper siting of facilities and infrastructure, agriculture, and public safety and health. For a more inclusive look at the ISGS' research and service pursuits, please request a copy, free of charge, of the "Illinois State Geological Survey: Science focusing on issues and trends; future needs." Should you wish more comprehensive, technical information, I invite you to request a copy of the Survey's scientific annual report.



Research Aimed at Improved Oil and Gas Recovery

Consider the fact that Illinois, 15th in oil output in the United States, produced almost 30 million barrels of oil just five years ago and now produces just under 20 million barrels of oil a year. Yet, research at the Geological Survey indicates that almost two-thirds of the discovered oil remains trapped within the reservoirs in the subsurface. In fact, the U.S. Department of Energy (USDOE) estimates that Illinois has 6.0 billion barrels of this unproduced oil. Much of this oil is residual, immobile oil that may be produced only with great difficulty and at prices considerably higher than today's prices. But about 1.5 billion barrels of this unproduced oil remains as mobile, bypassed oil in untapped compartments due to heterogeneities in the rocks in the subsurface. Some of this oil can be recovered using today's technologies and at today's prices if only we could better understand and predict the factors causing the compartmentalization.



Donald Oltz, senior geologist and head of the Oil and Gas Section, assists Dennis Haggerty, petroleum engineer, in taking a plug from an outcrop of the Aux Vases Sandstone. Scientists will study the porosity, permeability and other characteristics of this sample and compare them with geologic information from subsurface reservoirs in the same rocks.

Additionally, many wells in Illinois, which initially produce hundreds of barrels of oil per day, exhibit a production decline to less than 10 barrels a day (a stripper well). Caused in some cases by formation damage, this rate of decline can make wells uneconomical and discourages investments. Improved oil recovery is possible. It is needed.

While Americans' consumption of hydrocarbons, particularly those used for transportation fuels, continues its upward spiral, U.S. production declines—a trend since the collapse in oil prices in 1986. At an accelerated pace, major U.S.-based oil companies are shipping their capital for exploration and development overseas. Tens of billions of dollars that once would have been spent to drill wells or build refineries in this country are being earmarked for foreign operations. According to an analysis of 18 domestic companies by Petroleum Finance Co., the U.S. share of all their spending for exploration and development dropped from 60 percent in 1985 to 20 percent in 1990. Inevitably, the result will be a further decline in domestic oil production and increased dependence on imports, not just for crude oil but for refined products such as gasoline and jet fuel as well. Estimates indicate this country will import an average of 47 percent of its oil and gas in 1992.

While this trend will continue, geological investigations have shown that some things can be done at home to reduce the rate of decline and help in the event of another oil crisis. Work by the Illinois State Geological Survey, now in the third year of a program designed to increase Illinois' oil resources

and prudently develop them, has contributed to the results of these investigations. This program of improved oil recovery has been recognized as fitting in well with the objectives of the National Energy Strategy, which emphasizes the domestic oil supply and a reduction of imports.

To help increase oil recovery and aid economic development of the depressed oil industry in the state, the ISGS has an integrated, multidisciplinary team of geologists, reservoir engineers, geochemists, clay mineralogists, and computer experts analyzing and assessing oil reservoirs and studying the impact of reservoir heterogeneity on oil production. Goals of this major effort are to aid Illinois' independent oil producers in the recovery of higher percentages of oil from fields already discovered, develop new incentives to encourage exploration, promote logical development of Illinois' oil and gas, and provide relevant and timely information to the oil industry and the public through **technology transfer**—a major component of the project. Through outreach programs and workshops, which have already begun, researchers hope to encourage producers to apply promising techniques in drilling, completing, maintaining and managing reservoirs to maximize hydrocarbon recovery.

Program heralded, studies 15 fields

Representatives from industry and the USDOE have heralded the Geological Survey's four-year, $4.9 million program as a model. This matching state-federal cooperative venture is already providing information on hydrocarbon resources, reservoir characteristics, production methods and reservoir management. Researchers have made substantial progress in their pilot studies of the type and degree of reservoir heterogeneity in 15 fields producing from two of Illinois' most prolific oil-producing horizons, the Cypress and Aux Vases formations, and have already begun to publish their results.

To unlock the secrets to more efficient oil recovery in these horizons, the geologists are using many "tools"—from simple saws, grinders, and drills to seismic experimentation and a multitude of sophisticated instruments, including testing equipment, simulators, and workstations providing computerized graphics. Through thorough, intensive probings in the field and laboratory or at a computer and drafting table, they are getting a foothold on



Petroleum geologist Bob Cole labels a core sample of Cypress sandstone.

potential problems and conditions within reservoirs capable of impeding recovery of Illinois' oil.

To achieve a greater understanding of the hydrocarbon reservoirs, staff members have also undertaken an investigation of the features found in these same rock intervals exposed at the surface. They completed a statewide surface investigation of the Aux Vases Formation in 1990 and subsequently began a similar investigation on the Cypress Formation wherein the researchers are recording detailed observations and measurements and collecting samples for microscopic and other evaluations; thereafter, the geologist responsible for compiling the information is interpreting results.

In one specific aspect of this study, the scientists are making a highly detailed investigation of an extensive Cypress outcrop located on Interstate 57 near Anna. They are treating this outcrop as an analog of a petroleum reservoir, gathering information on an inch-by-inch basis. The scientists are describing the exposure in great detail and using sophisticated instrumentation to determine the permeability of the rocks (a measure of the ability of fluids to move through the rocks) as well as the amount of low-level gamma ray emissions from the rocks (indicative of how clean the sands are). With a high-powered drill, they are also taking samples for further testing in the laboratory. Results are then being compared with similar information gathered from selected oil-producing horizons in the subsurface.

In addition, staff members are compiling data from chosen wells in the oil-producing area of the state to be used in a regional study of the relationships among outcrops,

subsurface stratigraphy and hydrocarbon reservoirs. Cross sections, showing stratigraphic changes within these formations, and maps, showing reservoir distribution, will be constructed.

Technologies extrapolated to similar reservoirs

The Survey's geologists are also studying the composition of a reservoir using core samples examined by X-ray diffraction to determine the kinds and relative quantities of clay minerals present, which are often troublesome in oil recovery, and a Scanning Electron Microscope to determine the distribution and shape of pores in the rocks



Steve Sim, petroleum engineer, demonstrates a new state-of-the art pressure, volume and temperature (PVT) apparatus that simulates oil-production conditions in the laboratory. When oil is brought to the surface, a change in pressure, volume and temperature causes some oil loss in the form of gas. The ISGS can help oil producers calculate this loss with PVT equipment, which measures the decrease in the volume of oil as it comes to the surface and the amount of gas released at the surface. With the PVT, researchers can simulate carbon dioxide injections (used to enhance oil recovery) and measure oil swelling and viscosity reduction at reservoir temperature and pressure and calculate the potential increase in production. Fluid analysis data are useful for estimating oil and gas reserves in the reservoir, designing surface oil and gas separation equipment, planning production strategy and for enhanced oil recovery.

comprising the reservoir. Regionally, they are correlating these analyses with interpretations of similarities in depositional processes, reservoir geometries, and wireline log responses of reservoir rocks. To date, results indicate that similar modifications during and after deposition are responsible for development of reservoir characteristics in the Aux Vases over specific areas being studied. Knowledge of reservoir similarities will permit testing and subsequent extrapolation of specific technologies for improving oil recovery to other reservoirs.

Knowing the type of rock and clay minerals and their areal distributions across a reservoir are important factors for developing an optimal recovery system. Researchers have detected significant differences in clay content, types of clay minerals and cementing minerals that affect a well's productivity and, therefore, should be considered during drilling and completion. For instance, clays subjected to a fresh-water drilling mud may swell and plug rock pores, cutting off porosity and permeability, thereby diminishing oil recovery. In addition, acids, normally used to stimulate production or remove excess casing cement, can also harm recovery by reacting with certain clay minerals. Clay-mineral particles, when dislodged, can plug up pores. Forewarned, a producer can take appropriate measures while developing a reservoir/field.

Using other state-of-the-art apparatus, researchers in the ISGS' laboratories are flooding core samples from reservoirs with hydrochloric acid, different brines, fresh water, or other chosen fluid desired and are studying reactions to determine any possible mischief these substances can cause in a given reservoir. The fluids chosen for this research effort simulate those normally used in Illinois' oil fields. Then too, staff members are looking at reservoir fluids to predict reactions that influence porosity and permeability and changes in reservoir properties in response to the injection of fluids used in enhanced oil recovery. During this period, they have collected 39 samples of brine and oil from the Aux Vases and Cypress formations and are analyzing them for various physical and chemical attributes. The data will be used for computer modelling to forecast formation damage from the use of certain fluids.

In other experiments, also under simulated reservoir conditions, researchers vary pressure, volume and temperature of different oils to learn the optimal parameters for estimating oil and gas reserves and planning production strategies as well as for enhanced oil recovery studies such as the effects of injecting carbon dioxide into a reservoir.

Visuals (a variety of geologic maps, cross sections, well logs, photos of mineral deposits taken from microscopic/analyzer examinations of core samples, three-dimensional computer modelling of the subsurface, etc.) are very important to this

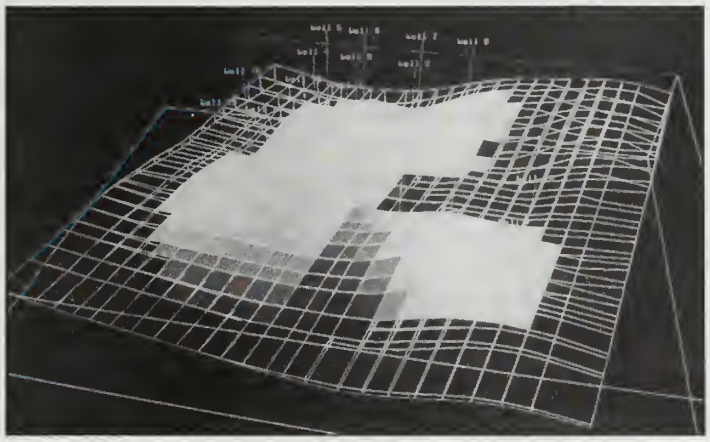


Using the new Silicon Graphics workstation, Emmanuel Udegbunam, petroleum engineer, at left, and Hannes Leetaru, petroleum geologist, take the results of oil-field studies into the next research phase: modelling reservoir characteristics and production data via three-dimensional color graphics.

research, allowing observations of the many complexities within a reservoir. Computer imaging capabilities permit researchers to see a reservoir take shape layer by layer, study the distribution of the sands, strip away non-reservoir rock, and filter information any way they choose. In fact, with such a graphic tool, they can strip out the characteristics desired, move them into a reservoir simulator, simulate a water flood with wells at various spacings, and observe the results—all from their workstations at the ISGS.

Thus far, the Survey's geologists have defined the types of reservoirs and characteristics of each, looked beyond depositional environments to post-depositional factors that have affected the reservoirs, and are learning how characteristics affect recovery of hydrocarbons. Because of compartmentalization, they have confirmed a need to alter Illinois' 10-acre well spacing when bypassed oil can be ascertained by geologic and engineering studies. The scientists have documented that clays are important factors within these reservoirs. Major players in reservoir damage, clay minerals, if not handled properly, are often detrimental to the recovery of oil.

This three-D display shows changes in pressure in the oil-producing formation over a period of time.



Focused studies, results

Examples of the results to date are provided by the following brief reviews of integrated studies of the Tamaroa, Bartelso and King fields. Tamaroa Field, which produces from the Cypress Sandstone, has been studied to evaluate the potential to increase its cumulative oil production and define recovery problems. Discovered in 1942, this field, located in northeast Perry County, produces just below 1,100 feet, principally from multiple lenticular stacked sandstones, separated by shales. Based on records of 32 of the 46 producing wells, the Tamaroa and Tamaroa South fields produced some 770,000 barrels through 1989, but only a few wells in Tamaroa South remain in operation today.

Comparison of the separate pools in this area shows similarities in the physical characteristics of the sandstone bodies. Scientists believe the depositional processes and settings for the sandstones were also likely similar. Intuitively, one might expect similar recovery efficiencies, but this has not been the case.

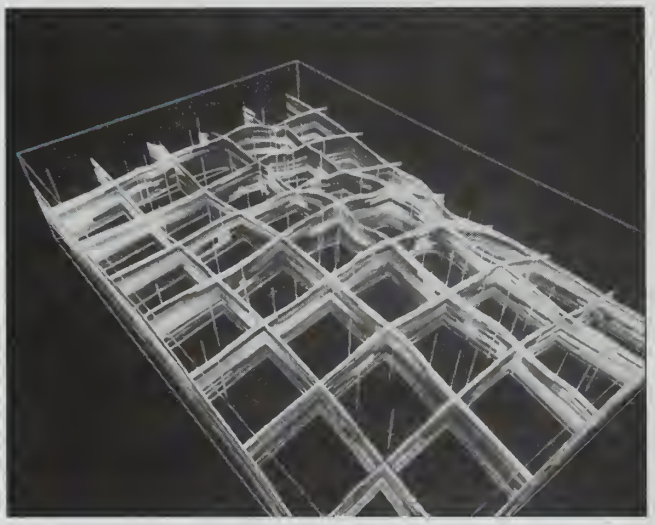
Within the multiple oil reservoirs of the Tamaroa and Tamaroa South fields, both marginal and successful production programs are apparent. Efficiencies in recovery have varied widely. For example, the Tamaroa Field, developed in two stages, had recovery efficiencies of five percent in the initial wells (attributable, in part, to release of gas pressure from the reservoir) to 43 percent, achieved by primary (pumping) and coordinated secondary (water flooding) recovery methods. Tamaroa

South, also developed in two stages, achieved 25 and 32 percent efficiencies using some water flooding.

The variable recovery is a result of reservoir heterogeneity, an understanding of these complexities, and the subsequent manner in which these fields have been managed. Reservoir management should be a combined program through all stages of drilling, completion, stimulation and development. Research indicates that more can be done to wisely produce these fields.... The study found that improved oil recovery techniques can increase production for the field by using developmental drilling; pressure maintenance; coordinated secondary (water flood) recovery programs; and where compartmentalization exists, different well-spacing practices.

Bartelso's development well managed

Another study detailing the rocks and structural factors that affect reservoir development and hydrocarbon recovery from sandstones in the Cypress Formation is



In the geologic model, a three-dimensional grid of cross sections (fence diagrams) is superimposed on a projection of wells drilled into the Aux Vases Sandstone, an oil-bearing reservoir. Rotating the grid, petroleum geologists can change the perspective of the subsurface rock formations, and using a zoom control, they can look at by-passed portions of the formations from which the oil has not been recovered.

that of the Bartelso Field, discovered in 1936, in south-central Clinton County. The management of this field represents a success story inasmuch as 50 percent (about 2.5 million barrels) of the oil has been extracted from 76 wells compared to one-third efficiency of recovery achieved by employing normal primary and secondary production methods in most reservoirs in the Illinois Basin. Well-coordinated water flooding covering multiple leases throughout the entire reservoir and varied well spacing were key elements in the high level of recovery at Bartelso.

The upper sandstones in the Cypress at Bartelso are shingled bars and the primary reservoir. The Cypress in that field has been subdivided into four separate sandstone intervals, the upper three of which contain oil and gas. Researchers have found that only the lowermost producing sandstone exhibits sufficient homogeneity to be efficiently drained with a 10-acre well spacing. Because of the complexities in the upper two producing units, closer well spacing was needed to optimize recovery.

Illinois' 10-acre well spacing for sandstone reservoirs was arbitrarily established with no geologic basis. Reservoirs deeper than 4,000 feet require an arbitrary 20-acre spacing, according to regulations. Such spacing criteria are waived with water flooding, allowing tighter spacing at Bartelso, where compartmentalized oil in the upper two producing units would have been missed otherwise. This study, in itself, points out the need for strategic infill drilling based on geology rather than arbitrary spacing.

Looking at the Survey's study of the King Field, one learns that the productive Aux Vases sandstone was formed in a nearshore, marine environment similar to the Bartelso Field. The King Field, located five miles southeast of Mt. Vernon, in Jefferson County, extends over 1,700 acres. It produces mainly at a depth of about 2,750 feet, although there is minor production from overlying and underlying reservoirs. From the original 17 million barrels of oil in place, 108 wells have produced 4.1 million barrels since 1942.

Although depositional environments were similar between the King and Bartelso fields, their efficiencies of recovery are quite different, King having less than 30 percent versus the 50 percent attained at Bartelso.

Post-depositional alterations occurred in the King reservoir, causing a high degree of reservoir heterogeneity. Chemical properties of the rock reservoir were altered. For instance, scientists found more clay and calcite in the reservoir at King than Bartelso. Calcite cement and clay made recovery of oil from the King Field more difficult. These influences on reservoir heterogeneity as well as compartmentalization resulting from depositional



Technology transfer is pictured with Kenneth McGee, petroleum geologist, pointing out a Cypress Sandstone reservoir to an oil producer. During a workshop, scientists presented and displayed intermediate results of field studies on the Cypress and Aux Vases formations in the Illinois Basin to independent oil producers.

conditions were not understood when recovery methods were applied.

As production steadily declined after 1966, there were no new water floods, outposts or infill wells. In fact, most of the wells were plugged and abandoned after the collapse of oil prices in 1986.

Significant areas unswept

Abandonment may have been premature, according to the Survey's researchers. Their study shows that compartmentalization in the reservoir at King Field has allowed significant areas to remain unswept by recovery efforts using water flooding. An estimated one to two million barrels of oil may be recoverable by primary and water-flood methods. Data, which will help implement improved or enhanced oil recovery techniques in this oil field, and areas where these techniques should be applied are presented in a report already released by the ISGS entitled "Reservoir Heterogeneity and Improved Oil Recovery of the Aux Vases (Mississippian) Formation at King Field, Jefferson County, Illinois."

Scientists at the Geological Survey believe that geologically-targeted infill drilling between existing wells combined with selective, well-designed water flooding may be able to recover up to 15 percent of the remaining primary reserves in the King Field.

Based upon such current studies, the Illinois State Geological Survey is developing an understanding of reservoir heterogeneities and the implications of reservoir management to handle these variations. Through seminars, workshops, poster sessions, and invited talks, staff members are already sharing much of this new knowledge with those who can put it to good use in the oil fields. Such **technology transfer** to operators and other representatives of the oil industry in Illinois has occurred a number of times during this reporting period. The scientists presented invited talks describing this research to members of the Illinois Oil and Gas Association, Illinois Oil Producers Association, the Kentucky Oil and Gas Association, the Illinois Stripper Well Owners and Royalty Association, the Eastern Section of the American Association of Petroleum Geologists (AAPG), the Fifth International Archie Conference, and the Illinois Geological Society.

In addition, the researchers have presented poster-style displays, showcasing their work at the Illinois Oil and Gas Association's annual meeting, attended by some 400 local geologists, oil company operators, and service company representatives. Exhibits were also presented at the AAPG's national meeting, attended by more than 6,000 national and international representatives of the petroleum industry, and the Eastern Section meeting of AAPG.

The payoff for employing enhanced recovery techniques suggested by this research is handsome. Consider the fact that the state's 1990 oil production of 19,900,000 barrels had a value of more than $398 million at $20 a barrel. Of the estimated 6.0 billion barrels of by-passed oil left in reservoirs across the state, some 1.5 billion barrels represent mobile recoverable oil. If the application of technology developed during this program resulted in an increased production of 10 percent of these 1.5 billion barrels of unswept mobile oil, at $20.00 a barrel, the value of incremental production in Illinois could equal $3.0 billion....

And if the application of this technology opened up Illinois' oil fields, other positive ramifications would accrue such as an improved economy in the depressed oil-field areas of Illinois.

Protection Crucial to Groundwater's Quality, Usability

Water, although a necessity for all living things, is also a key to future economic growth. While its use in this country over the past 40 years has more than doubled, this vital resource has been and remains very vulnerable to contamination.

Will there be water for future generations? Will it be suitable for consumption? How will water be protected from human activities that could be spoiling its use?

While not fully funded, the Illinois Groundwater Protection Act mandates activities that will provide information to help balance protection and use of the groundwater resource. It calls for developing a coordinated groundwater data collection and automation system, including results of groundwater monitoring and collection of well logs, pollution source permits, and water quality assessments; developing and administering ongoing basic and applied research; and making results and information available to local governments seeking assistance. Activities, to be carried out by the Department of Energy and Natural Resources (ENR), of which the ISGS is a division, include the following:

1. long-term statewide groundwater monitoring;

2. statewide assessments of groundwater resources to enhance the data base by locating resources, mapping aquifers, identifying appropriate recharge areas, and evaluating base line water quality;

3. evaluating the impact of pesticides on groundwater; and

4. other basic and applied research, including groundwater hydrology and hydraulics, movement of contaminants, and technologies for the restoration and remediation of aquifers.





On the left, Dennis McKenna, geologist in the Groundwater Protection Section, uses a baler to remove groundwater samples from a monitoring well located next to a stream. Above, he purges the monitoring well before obtaining a fresh sample that is more representative of the water found in the aquifer.



For their study of groundwater's contamination by atrazine, scientists found this farm south of Urbana that met all of their criteria: corn and soybeans in rotation, presence of a tile-drainage system, past and current use of atrazine, relatively uniform soil and geologic conditions, co-location with existing water quality studies by state or federal agencies, and cooperation of the landowner.

Among programs that have received funding are ones investigating the impact of pesticides on groundwater and groundwater assessments. Concern over the potential for contamination of groundwater by agricultural chemicals is founded on the following facts:

- Two out of three acres of rural Illinois are treated with agricultural chemicals— some 50 million pounds of pesticides and a million tons of nitrogen fertilizer annually.
- More than 80 percent of the corn and nearly 30 percent of the soybean acreage receiving preplant or preemergent weed control in 1990 was treated with herbicides that pose a potential hazard to groundwater in vulnerable soil and hydrogeologic settings.
- Groundwater is the only source of drinking water for about 97 percent of the rural population in this state.
- Aquifers occur within 50 feet of the ground's surface in about 40 percent of rural Illinois.
- State and county agencies have detected pesticides in samples of groundwater from shallow aquifers. However, public water wells that normally withdraw water from deep aquifers apparently have not been significantly affected.

Thus, accurate prediction of the vulnerability of groundwater resources to contamination from agricultural chemicals (pesticides and nitrates) is one of the most important environmental issues facing farmers, water users and governmental agencies. With current agricultural practices and technology, leaching of agricultural chemicals—particularly nitrates derived from fertilizer nitrogen and the more mobile pesticides—into groundwater may be impossible to prevent. Areas most vulnerable to contamination must be identified to effectively target educational programs, technical assistance, and detailed monitoring studies of groundwater resources in the state.

Regulation of the use of agrichemicals must also take into account the vulnerability of groundwater resources. The USEPA has published a strategy to regulate the use of pesticides to prevent unacceptable levels of contamination in current and potential supplies of drinking water. It recommends managing the use of pesticides on the basis of differences in the use of groundwater, its value and vulnerability. The agency also recommends using the vulnerability of groundwater as a basis for county- or state-level measures, which may include cancelling the use of specific products.

If water is under protected, it may become contaminated, detrimentally affecting users. On the other hand, over protection of this resource could result in restrictions in areas that do not require stringent protective measures, resulting in economic hardship. Thus, an optimum level of protection for groundwater should balance the use of

agricultural chemicals and protective measures. Research relating to the effects such chemicals are having on Illinois' aquifers is under way at the ISGS.

In support of the state's Pesticide Management Plan being developed by the Illinois Department of Agriculture (IDOA), the Geological Survey's scientists are using knowledge of groundwater flow, soil and rock/water interaction, and statewide geologic maps to identify regions with aquifers vulnerable to contamination by agricultural chemicals.

Precipitation, source of groundwater

Illinois' source of groundwater is precipitation that infiltrates the soil and percolates downward to the water table. The replenishment of groundwater, known as recharge, depends upon the moisture conditions of soil, its permeability and water retention capacity, type and distribution of vegetation, duration and intensity of precipitation, and location within the groundwater-flow system. Regionally, the interrelationship of surface soils, underlying geologic materials, and configuration of the landscape determines the rate and amount of recharge and the direction of shallow groundwater flow. Tile-drainage systems in agricultural areas may alter natural drainage and recharge. Recharge does not occur at specific points or in small areas; some recharge occurs in all unpaved areas except the discharge areas. Streams in Illinois that flow all or most of the year are groundwater-discharge areas. Water will infiltrate to the water table over the entire interstream area; some water will move upward through evaporation from the soil and transpiration from plants, while the remainder will move downward into the saturated zone. Some of this water will discharge into nearby streams with the remainder moving deeper into the regional groundwater-flow system.



Zhenkun Zhao, left, and Lettie Schmitt, both lab assistants in the Geological Survey's Environmental Geology Laboratory, are measuring the uptake of pesticides by soil.

The movement of groundwater is directly related to the permeability of geologic materials and the hydraulic gradient. In areas directly underlain by permeable bedrock or sand and gravel, relatively rapid infiltration and movement will occur. However, in areas underlain by silty or clayey materials, surface runoff may be greater and the movement of groundwater generally slower, providing considerably less recharge to aquifers than in areas composed of sand and gravel or permeable bedrock at or near the surface. Thus, the vulnerability of an aquifer is estimated on the basis of the thickness and character of materials overlying it. The character of the materials affects the rate of movement and the degree of attenuation (reduction in the concentration of a pesticide); the thickness affects the time to reach an aquifer, allowing more time for attenuation.

For the project with IDOA on identifying regions with aquifers vulnerable to contamination from agricultural chemicals, the Survey has mapped Illinois at a scale of 1:500,000 (one inch equals approximately eight miles). It is also providing county maps developed at 1:250,000 (one inch equals approximately four miles). A report will accompany each map and summarize the factors and processes affecting the transport of agricultural chemicals to groundwater resources.

The interpretive maps are based on the distribution of the Earth's materials. Highly permeable materials (sands, gravels, fractured carbonate rocks, and sandstones) will generally allow rapid migration of contaminants. Materials of relatively low permeability (loess, glacial till, shales, cemented sandstone, and unfractured carbonate rocks) generally restrict contaminant migration. Thickness of fine-grained materials controls the susceptibility of the underlying aquifers to contamination; the thicker the sequence of fine-grained material between the source and the aquifer, the less likely the aquifer will become contaminated. In addition, the concentration of a chemical may be reduced by natural processes (degradation, dilution, adsorption) before it reaches an underlying aquifer.

Distribution of geologic deposits

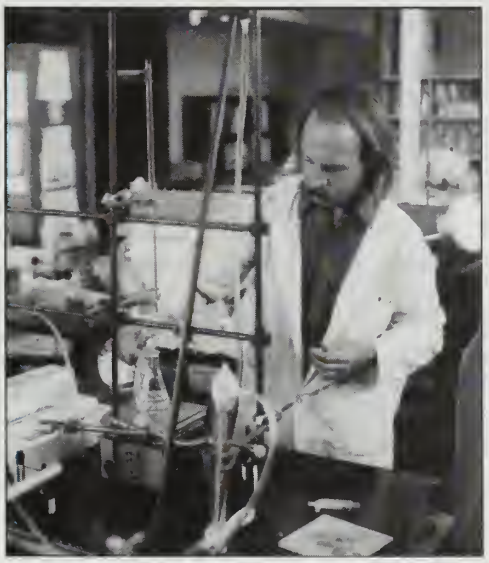
To map the potential for contamination of aquifers by agricultural chemicals, scientists used geologic information compiled from the Stack-Unit Map of Illinois published in 1988 by the ISGS. (The mapped units depict the distribution of geologic deposits vertically from the surface to a depth of 50 feet as well as horizontally over a specified area.) Staff members combined sequences of materials into four groups differentiated on the basis of distance from the land's surface to the top of the first continuous deposit of aquifer materials. In addition to the nature of earth materials, other factors, including the amount and properties of a given chemical and climatic factors, also need to be considered in determining the ultimate potential for contamination.

According to the maps and report prepared for the study entitled "Potential for Agricultural Chemical Contamination of Aquifers in Illinois," areas with intensive corn and soybean production and aquifer materials within 50 feet of the Earth's surface are most vulnerable to contamination. Scientists based this interpretation on their present understanding of the persistence of pesticides and rates of groundwater movement coupled with the results of studies on pesticides made in Iowa and Minnesota, which showed that pesticides were most commonly detected in shallow aquifers.

In approximately 40 percent of rural Illinois, aquifers lie within 50 feet of the ground's surface. These shallow aquifers occur throughout the state but are most common in the northern and southern parts and along the major river valleys. In about 60 percent of Illinois' rural areas, aquifers are more than 50 feet deep and apparently protected from contamination by agricultural chemicals by the attenuation capacity (all physical, chemical and biological processes that reduce the concentration of a pesticide) of soils and thick sequences of fine-grained materials. The use of pesticides, largely for corn and soybean production, is heaviest in areas of Illinois where aquifers are generally **least vulnerable** to contamination....



Phil Reed, geologist in the Hydrogeology Section, lowers a sonde into an observation well to determine the sequence of earth materials.



In the Environmental Geology Laboratory, Bill Roy, geochemist, examines an extract of a soil sample.

Additionally, in response to mandates of the Illinois Groundwater Protection Act for ENR to carry out basic and applied groundwater research, scientists from the ISGS and the Illinois State Water Survey (ISWS), in cooperation with the IDOA, are conducting a pilot study to evaluate the impact of pesticides and nitrates on groundwater in five representative hydrogeologic settings in the state. While providing a preliminary estimate of the occurrence of agricultural chemicals in rural private water supplies, the pilot program is helping evaluate components of a recommended statewide survey for agricultural chemicals in rural wells.

Besides evaluating analytical methods, the study has tested procedures to inventory sites of wells, conduct interviews with

users of the wells, and collect water samples. Sampling of 48 randomly-selected rural water wells was completed in February 1991. Analysis of 240 water samples taken from these wells for 39 agricultural chemicals extensively used in Illinois (particularly pesticides with a high potential to move through the soil), nitrate, and nitrite were completed during the year. Using the USEPA's methods employed in the National Pesticide Survey, the ISGS determined 20 of the compounds, while the ISWS and Department of Agriculture analyzed other compounds. Reports describing the characterization process and the overall project are in preparation for the funding agencies—the Illinois EPA (IEPA) and ENR.

This project will establish base line data for pesticides in groundwater in several hydrogeologic settings and will help evaluate criteria for predicting the potential for contamination of rural wells. If scientists can more accurately estimate the occurrence of agricultural chemicals in wells in various hydrogeologic settings, they may be able to develop a tailored sampling program that can better characterize and forecast potential problem areas as well as result in a more cost-efficient sampling effort statewide. From these results, other agencies could target educational and monitoring programs for groundwater to areas of greatest need....

Base line studies

In a separate study, in accordance with mandates of the Illinois Groundwater Protection Act and in response to the public's concern over potential contamination of groundwater by agricultural chemicals, the IDOA, the state's lead agency for pesticide regulation, initiated a survey to provide statistically reliable estimates of the occurrence of agricultural chemicals in rural, private water wells in the state. Of the estimated 440,000 private water wells in Illinois, approximately 360,000 are in rural areas.

The Geological Survey is cooperating with the Department of Agriculture and the Cooperative Extension Service of the University of Illinois at Urbana-Champaign in this statewide project in which groundwater samples are being collected from approximately 340 randomly-selected wells and analyzed for nitrate, nitrite, a number of pesticides and metabolites. Sampling began in March 1991.

Primarily responsible for development of the sampling plan and procedures for collecting samples, the ISGS is also providing



Ivan Krapac, geochemist, spikes a field sample of groundwater with a known concentration of a pesticide for which analyses will be made in the laboratory. These spiked samples check on the accuracy of lab analyses.

geologic characterization of the areas in which samples are being collected and will assist in interpreting the final results. Relationships among the quality of well water, use of agricultural chemicals, and the vulnerability of an aquifer will be investigated in the statistical analysis of results from this survey.

Because no complete list exists of the rural, private water wells in the state, scientists used a two-stage probability sampling plan. In stage one, they randomly selected 200 land sections and developed a complete list of all dwellings and private wells within the rural area of each section. In stage two, staff members randomly selected approximately 340 private water wells from the list of wells in the rural area of each section containing such wells, acquired permission to sample wells, and conducted interviews with the users of the wells.

Researchers are collecting samples over a 13-month period, scheduled to spread collections across all seasons and periods for applications of pesticides and fertilizers. In addition to data they acquired from the well-user interview and well-site-characterization form, they are compiling soil and geologic data for each site.

Results of this statewide survey will provide the first statistically reliable estimates of the extent of contamination caused by

agricultural chemicals in rural, private water wells in Illinois. The survey should also provide some information on the factors affecting contamination of private wells. By identifying areas where private wells are more vulnerable to contamination and by identifying pesticides that are more likely to cause contamination, the study may provide a basis for more accurate targeting of future monitoring programs in the state....

In yet another project with the IDOA, the Geological Survey is assisting in addressing the 1990 amendments to the Illinois Pesticide Act which require the Department of Agriculture to develop guidelines and recommendations, including long-term financial expenditures which may be necessary to remediate contamination caused by pesticides.

Through this reporting period, the ISGS has completed a review of alternative sampling plans for selecting specific agrichemical facilities for on-site assessments. Scientists have performed an initial screening of the potential for aquifer contamination at 50 randomly-selected facilities, based on existing geologic mapping at a scale of 1:250,000. In addition, the Geological Survey has provided assistance in developing technical standards for conducting phase 1 and 2 environmental site assessments at 20 agrichemical facilities. The actual evaluation and assessment of conditions and operational practices at these facilities will be conducted by other contractors....

Studies on fate of atrazine

Subsurface movement of atrazine, a herbicide, and de-ethylatrazine and deisopropylatrazine, primary degradation products of atrazine, are being studied to estimate the relative contribution of surface-water runoff and shallow groundwater discharge to pesticide loadings in streams. A small watershed in east-central Illinois is the focal point of this study.

Atrazine and its degradation products were present in water samples from the stream throughout most of the year. Concentrations of atrazine in individual water samples ranged from 4.9 micrograms per liter in late May to less than 1.0 microgram per liter during June. The average concentration of atrazine in samples exceeded one microgram per liter in the five sampling periods from April 17 to May 29, 1991, except for samples collected on May 1. Atrazine was applied to cropland in the watershed from late April through early May. This high concentration of atrazine coincided with increased surface-water runoff and stream discharge in response to more than nine inches of rainfall during the month. The occurrence of these compounds in water samples from the stream during the remainder of the year may be the result of the discharge of groundwater into the stream, discharge of tile-drainage water, or desorption (detachment) of atrazine from stream-bed sediments.



A mobile drill rig was used to install eight 13-foot-deep nests, six nests in the field and two in the stream. The six field nests included a water-table monitoring well and three piezometers (one to measure depth of water table and the other two to measure water pressure within the till and the sand).

The adsorption (attachment) of atrazine by surface soils is well understood, but few studies exist on the movement of atrazine in deeper materials containing low levels of organic carbon. Research indicates that this pesticide's adsorption by such materials may be under estimated. Laboratory measurements disclosed that the extent of atrazine adsorption may be one to five times greater than predicted by the organic-carbon content, an observation consistent with other studies.



A continuous soil core was collected to a depth of four meters at each nest site when the wells and piezometers were installed. Samples from these cores will be used for adsorption studies of atrazine.

Measurements have indicated that atrazine does not desorb (detach) readily during short-term intervals. As the organic-carbon content increases, the degree of irreversibility also increases. This lack of reversibility may be the result of slow desorption or a reaction of atrazine with the organic matter to form chemical bonds. However, once below the surface soil, atrazine's subsequent migration will be slightly retarded by adsorptive-desorptive interactions, depending on the distribution of organic matter in the subsurface and the acidity or alkalinity of the groundwater. Studies with de-ethylatrazine will begin next fiscal year. This research is being funded by the U.S. Department of Agriculture's Cooperative State Research Service through the Groundwater Research Consortium of Southern Illinois University at Carbondale....

And more

Researchers also evaluated the utility of monitoring drainage-tile effluent for pesticides as a potential alternative to the installation and monitoring of large networks of groundwater-monitoring wells. They collected samples from drainage tiles, soil-water samplers, monitoring wells and soil. Results demonstrate that pesticide concentrations in drainage-tile effluent can be used to evaluate the leaching behavior of these compounds in the field, provided certain information is known regarding the layout of the tile system and the local hydrogeologic setting....

To clarify potential problems of regional contamination caused by agricultural chemicals, the USEPA Region V also supported the production of a Contamination Potential Map of the Chicago Sheet, covering parts of Illinois, Indiana, Ohio, Michigan and Wisconsin. This map was produced in a cooperative effort by the USGS and the ISGS, using the USGS' texturally-based, three-dimensional maps. Currently, the USGS is statistically evaluating the validity of information portrayed, comparing contamination potential units on the map to actual contamination of wells by nitrates.

Again responding to the Groundwater Protection Act, the Survey has generated a map, "Potential for Aquifer Recharge in Illinois," which shows recharge areas based on depth to aquifers and surface-soil infiltration. It can also be used to evaluate the potential for contamination of aquifers....

The ISGS and the ISWS, in cooperation with the IEPA, are using the new recharge map and a number of other geologic maps in a detailed pilot study of the geologic and hydrologic aspects of the Woodstock area. The study will establish methodology for making groundwater protection needs assessments to be used in assisting local governments with evaluating aquifer characteristics and defining areas of potential contamination.

Thus far, scientists at the Surveys have compiled preliminary versions of cross sections, isopach maps of four aquifers that were discovered in the area, a stack-unit map of materials to a depth of 100 feet, and a map depicting the potential for contamination of aquifer materials for the Woodstock 7.5-minute topographic Quadrangle. They are also statistically analyzing the chemical data and drafting reports.

Pressure is mounting for more detailed geologic mapping statewide. Such maps are being used as tools to investigate and solve environmental problems, aid in resource management, and help prioritize geographic areas most in need of evaluation, monitoring, or perhaps remedial technology.

Geologic Mapping Provides Problem-Solving Information

Because the Earth's materials are essential to modern life and their consumption can cause environmental problems, mankind needs to understand their nature and distribution. After all, the populace lives and depends on these materials, extracting water and minerals from them; depositing waste in them; constructing roads, dams, and buildings from and on them; and is affected by hazards, like earthquakes, landslides and subsidence, involving them.

Geologic maps provide information which mankind can use to help solve its many earthbound environmental and resource-related problems. Such maps illustrate the character of materials at or below the ground's surface, depicting soils of various types, sand or sandstones, silts or siltstones, clays or shales, limestones or dolomites, varieties of glacial deposits, coals and other mineral resources, their ages, physical character, and lateral and vertical distribution.



Looking over a sand isolith map of Lake County to be used to help site a landfill are Don McKay, senior geologist and head of the Geological Mapping and Digital Cartography Section, Lisa Smith and Bob Pool, geologists. The map was prepared using GIS software.

How much information can be presented on a geologic map? A map's scale determines the detail shown. The geology of the entire state on one sheet of paper, even if it is a large wall map, does not permit much detail. On the 1:500,000-scale geologic map of Illinois, for example, one inch represents about eight miles on the ground; 1/32 inch, about the thickness of a heavy line, equals 1,320 feet on the ground. Maps that permit representation of greater detail are the 1:24,000-scale 7.5-minute topographic quadrangles. On these maps, one inch represents 2,000 feet on the ground, permitting about 20 times the resolution of statewide 1:500,000-scale maps. Although a line 1/32-inch wide on the 1:24,000-scale map still represents about 62 feet on the ground, this scale allows city blocks to be shown without difficulty.

While regional geologic map coverage of Illinois is available at scales from 1:500,000 to 1:250,000, a lack of funding has prevented the development of statewide geologic maps at scales detailed enough (1:24,000 to 1:100,000—one inch equalling 1.6 miles) for today's planning and decision-making purposes, focusing on rapidly increasing environmental concerns and continuing pressures for and from economic development.

Such highly detailed geologic maps often are required for decision making by industry in locating resources, siting facilities, and undertaking construction projects. Municipal, county, state, and federal governmental agencies need the same kinds of maps for planning purposes and assessing competing land uses; selecting areas where geologically appropriate sites

for landfills and even nuclear waste disposal facilities are likely to occur; selecting areas where facilities such as hospitals or schools can be safely located; developing zoning regulations; and assessing the value of land. Private, public and governmental sectors need these highly detailed geologic maps for the development and protection of groundwater resources and to identify hazards and assess the potential damage from earthquakes, landslides, subsidence and coastal erosion.

The principal source of geologic maps for Illinois is the ISGS by virtue of mandates of the General Assembly and the Survey's tradition of investigating and reporting on the geology of Illinois. While statewide maps exist on regional scales, only three percent of the state is covered by published maps at the detailed 1:24,000 scale required for many current applications. The only sizeable areas with adequate coverage at that scale are the Illinois Kentucky Fluorspar District of southeastern Illinois, the adjacent coal-field area in southern Illinois, and the Chicago area of northeastern Illinois. These maps are accompanied by detailed geologic reports. The Chicago-area maps were published in the 1940s; the Fluorspar District maps, in the 1960s; and maps of the coal-field area, in the 1980s and 1990s.

Mapping area, rich in resources

The latter maps are part of an ongoing geologic mapping program that has been supported since 1984 by the USGS and the State of Illinois under the Cooperative Geologic Mapping Program (COGEOMAP). This region of southern Illinois, while rich in some areas in such mineral resources as coal, oil, gas and fluorspar, is underdeveloped. The geology of the southernmost portion of the region is more complex than other parts of the state, and its details are only now beginning to be understood.

Through COGEOMAP, renewed efforts by the Survey's mappers have located new seams of coal. However, these are generally thinner and less easily mined than other coals in the state, and their sulfur content is not as low as expected. Detailed mapping also is changing geologic concepts of the region in ways that could provide new tools for successful exploration of oil and gas. Faults outside the Illinois Fluorspar Mining District have been mapped in detail and are potential targets for mineral exploration.

The original COGEOMAP program calls for the publication of 16 7.5-minute geologic quadrangles; six of these have been published and three are currently in production. Another four quadrangles in southwestern Illinois were added this year for mapping by 1993.

Further expansion of the COGEOMAP program in Illinois during this reporting period brings the mapping effort into the east-central part of the state. The USGS has awarded the Survey a contract to develop an advanced methodology for three-dimen-



While in the field working on the Cooperative Geologic Mapping Project (COGEOMAP), a scientist climbs a limestone outcrop along the Mississippi River in the Grand Tower area.

sional mapping of Quaternary (glacial) deposits in the Champaign 1:100,000-scale, 1/2-by-1-degree Quadrangle.

Through the Conterminous U.S. Mineral Assessment Program (CUSMAP), a cooperative project among the USGS and the State Geological Surveys of Illinois, Indiana, Kentucky and Missouri, geologic information is being summarized on maps at the 1:250,000 scale (one inch equals approximately four miles) from an original compilation at a 1:100,000 scale for a 5,000-square-mile-area of Illinois south of Benton and DuQuoin. This project provides detailed geological, geochemical and geophysical (seismic, gravity and magnetic) studies in regions known to contain or have potential for mineral deposits such as fluorspar, lead, zinc and industrial minerals (sand, gravel, limestone) and others. Its goal is to develop sufficient knowledge to determine the likelihood of finding new mineral resources or extensions of known deposits in the Paducah 1-by-2-degree Quadrangle, covering approximately 7,500 square miles in the states involved.



Barb Stiff, GIS specialist, Mike Sargent, seated, geologist in the Basin and Crustal Analysis Section, and Jim Baxter, senior geologist and head of the Industrial Minerals and Metals Section, examine a map showing potential veins of fluorspar in Illinois. Assessment maps for about 20 commodities and many intermediate maps were produced digitally for a Paducah CUSMAP meeting.

The ISGS has coordinated much of this research effort and data input and, with the USGS, has taken the lead in developing a computer data base for the ISGS' Geographic Information System (GIS) that incorporates new techniques in computer-assisted spatial data analysis and cartography for the Paducah CUSMAP project. Scientists have completed research and acquisition of data and, using the GIS, have prepared maps showing areas of high, moderate, and low potential for mineral discovery. They will release results of the resource assessment at a public meeting in January 1992.

GIS integrates, synthesizes data

The efficacy of the computer technology for assessing mineral potential was demonstrated in April 1991 at a workshop held in Champaign. As the name GIS implies, the geographic or spatial nature of information is fundamental. Geographic location of natural and cultural features provides a framework in which diverse data can be compiled and integrated to discover relationships and generate new information. The GIS' functions of integration and analysis provide a mechanism for combining information, testing multiple scenarios, and presenting the results in map form that is easy to understand. Thus, the GIS can be an invaluable tool for integrating and synthesizing information required to make critical choices and solve problems that face Illinois.

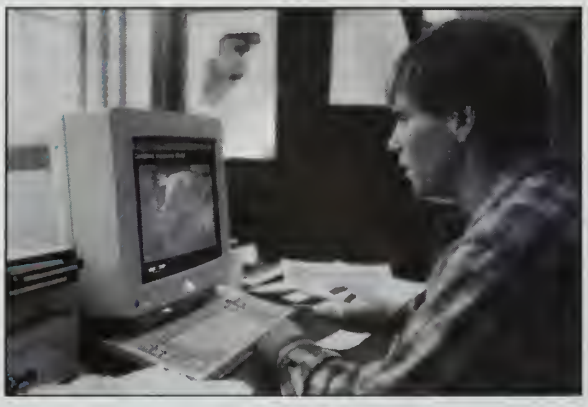
In using the GIS as a tool to assess resource potential for CUSMAP, geologists initially wanted to translate all available data into a digital format and use the GIS to calculate the relative potential for each type of mineral deposit. Thus, they developed techniques for digitizing maps and translating numerous types of data into the GIS format.

To produce a map depicting an area of relative mineral potential, the scientists created a digital model of deposits for each mineral, using descriptive deposit models that defined diagnostic criteria and quantified numerous criteria describing ore deposits. For example, permissive, necessary and critical criteria were specified in many of the descriptive models. While creating quantified digital models from the descriptive models, staff members needed a numeric weighting scheme to reflect the relative importance of each criterion. This process involved selecting the most important diagnostic criterion necessary for the occurrence of the mineral deposit being considered and assigning its presence an arbitrary high-value weight. Other criteria were assigned lesser weights relative to their individual importance in the model. Weighted criteria were then combined.

When all of the layers of a deposit model were combined using the GIS overlay technique, areas of relative resource potential were drawn. Based on the total model weight assigned to each area, those with higher and lower potential for mineral occurrence could be identified.

The purpose of these maps is to highlight areas which might have mineral resources—areas which could be targets for future research and exploration.

Upon completion of the project, the ISGS with the USGS will publish a series of reports on the geology and mineral resources of the Paducah Quadrangle. These will include new and innovative compilations of resource data related to coal, oil, gas, and the industrial mineral and metal resources; detailed surficial, bedrock and subsurface maps and cross sections; topical studies; and a general assessment of the mineral potential of the area. Availability of this information coupled with the development of new theories and models could make southern Illinois more attractive for mineral exploration and entrepreneurial activity.



Bob Pool, GIS geologist, views a model created for the CUSMAP study.

Rock units, structures identified

Besides showing topographic elevations and geographic features, a detailed geologic map uses various colors and symbols to show the relationships of rock units that are exposed at the surface. One such map, the Equality Quadrangle, covering an area in Gallatin County near the village of Equality, also shows the location of major coal seams and where the coals have been mined out. By knowing the lateral extent and thickness of the coals and what's been mined, one can estimate the quantity of coal remaining. This detailed map also identifies structures such as faults. In nearby areas, faults have trapped oil or have contributed to the formation of other mineral resources such as fluorspar. Thus, these maps convey information useful in assessing the potential for discoveries of oil and gas and other mineral resources. They also provide basic information and ideas useful to industry in exploring and developing the state's resources.

Detailed geologic maps can be especially helpful in resolving issues related to the environment, for example, in protecting groundwater resources from contamination. A map of Boone and Winnebago counties, originally compiled at the scale of one inch equals 2,000 feet, was printed at the more reduced scale of 1:62,500—one inch equals about a mile. This particular map was derived from the detailed geological map, called a stack-unit map, which shows the nature of earth materials down to a depth of 20 feet. The derivative map depicts areas more susceptible to the contamination of groundwater. In particular, sands and gravels and the fractured bedrock (a significant aquifer in the area) occurring within 20 feet of the surface are differentiated from areas less susceptible—the more impermeable glacial materials (tills) that are more favorable for landfills. These tills act as barriers to contamination of groundwater resources.

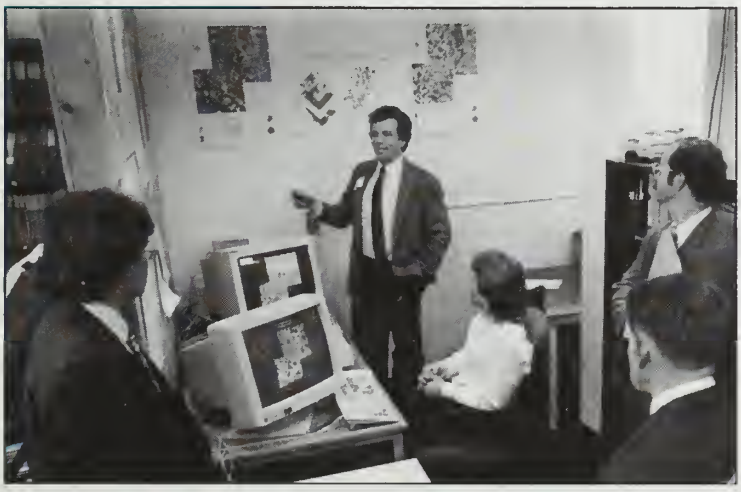
Unfortunately, before the need for this type of information became known and before these maps could be developed for Boone and Winnebago counties, numerous landfills had already been located in the areas most susceptible to the contamination of groundwater. Leakage from existing landfills into groundwater was virtually assured. To date, some four Superfund Sites, subject to clean up, have been identified in Winnebago County. Cleaning up those sites will be very costly. (Published figures indicate that the average cost of cleaning up a Superfund Site is between $20 million and $30 million.) If these kinds of geologic maps had been available when applications for these disposal sites were being considered, the need for and cost of clean up might have been avoided. Landfill applicants and public officials would have known the more geologically favorable areas and could have located the landfills accordingly. The cost of the project to develop this map for the two counties was approximately $250,000—an investment, which, if made even earlier, could have helped avoid future multi-million-dollar-clean-up costs at the Superfund Sites, giving some appreciation of the pay back possible from this type of detailed geological mapping.

Benefits, costs analyzed

In a definitive study for Boone and Winnebago counties, the Survey quantified the benefits of detailed geologic mapping.

Staff members compared the benefits to the cost of mapping discussed above. The return on an investment of $300,000 in 1990 dollars was about 23 to 54 times the investment for the best-case scenario and 5 to 11 times the investment for the worst-case scenario. The most probable case indicated benefit/cost ratios of 11.7 to 27.2. Benefits were calculated from avoided costs associated with the clean up of landfills and industrial disposal sites. The benefit/cost analysis excluded other benefits that are not currently quantifiable such as identifying and recovering the Earth's resources and providing basic data to industry and government for siting facilities—data indicating water supplies, foundation conditions, and areas suitable for the installation of septic tanks. Such benefits would increase the benefit/cost ratios significantly, just as they have in Kentucky.

Over an 18-year period in the 1960s and 1970s, Kentucky was mapped at this detailed scale at a cost of $21 million. Since then, the maps have been used extensively. The Kentucky Geological Survey estimates that the cost of the mapping has been repaid to the state at least 50 times over, coming from new coal mines opened in areas where new coal resources were mapped and from new oil and gas wells drilled into oil and gas reservoirs near faults that had previously been unknown. In addition, the pay back has come from savings derived from locating new highways that avoided landslide-prone areas. The maps also found widespread use in siting farm ponds and industrial facilities in Kentucky.



County officials listen to Rob Krumm, center, geologist, and Curtis Abert, assistant, seated, of the Geologic Mapping and Digital Cartography Section, who are explaining computer mapping used for regional screening to determine areas geologically capable of being landfill sites.

The ISGS prepared a report, "Geologic Mapping for the Future of Illinois," for the Illinois Senate Committee on Geologic Mapping and presented it in July 1991. This report included a detailed analysis of geologic mapping needs and prioritized the mapping of the 1,073 7.5-minute quadrangles in the state. Based on prioritized needs and uses, detailed geologic maps are required in Illinois to:

- ensure sufficient present and future supplies of groundwater;
- protect groundwater in areas of high usage and help assess the impact of agricultural chemicals on the quality of groundwater;
- plan landfill sites in the most populated counties or rapidly developing corridors with high priority given where capacity is most limited and where county plans indicate imminent need for a suitable site;
- assess geologic and related hazards, especially seismic risk and threat of landslides, coastal erosion and subsidence;
- select sites for development, especially in areas of rapid growth;
- permit comprehensive assessment of strategic and critical minerals;
- identify location and extent of deposits of sand, gravel, limestone, dolomite and other industrial minerals for the entire state, giving highest priority to metropolitan areas where construction needs are greatest;
- locate deposits of low- to moderate-sulfur coal;
- determine the nature and structure of bedrock, useful, for example, in the exploration for and development of oil and gas;
- introduce the public to Earth Science in parks, national corridors and other recreational areas.

Such maps are required to aid in economic development, environmental protection and risk assessment. The recommended geologic mapping program, designed to meet these expressed needs in priority order, is a long-term, multi-year effort, requiring dedicated funds. The recommended level of state funding for this program is $1.1 million per year over a period of 50 years.

Mapping, very restricted

Currently, the geologic mapping effort operated by the ISGS under the General Revenue Funds includes a staff of 2.9 full-time staff equivalents with an annual expenditure of approximately $170,000. During the decade of 1982-1991, the ISGS will have mapped 43 7.5-minute quadrangles and published them at a scale of one inch equals one mile or more detailed under the COGEOMAP and pollution prevention programs. Included are about 16 quadrangles in Boone and Winnebago counties, about 18 in Champaign County, and nine in the coal-field area of southern Illinois. The total effort is small and restricted geographically and functionally. At this rate, more than 200 years would be required to completely map Illinois at a detailed scale. The pressures of environmental and economic concerns will not permit such a slow timetable in Illinois.



Geologist Joe Devera examines a fossilized log in a bedrock outcrop in southern Illinois.

Similar needs exist in every other state except Kentucky and possibly Massachusetts, Rhode Island and Puerto Rico, which have been mapped at the suggested detailed scales. Mapping Kentucky and the other states was aided by the availability of detailed topographic maps at a scale of one inch equaling 2,000 feet. These maps are now available for all of the lower 48 states, thus making more detailed geologic mapping feasible.

Obviously, a state and federal program of geological mapping is needed. Pay back may be expected on the basis of saving clean-up costs of disposal sites alone. Other benefits will accrue in the delineation of mineral resources that will aid in building and rebuilding the nation's infrastructure; in the delineation of groundwater resources and their potential for contamination; and in the delineation of geologic hazards and their risk to public health, safety and property. Proposed legislation, if enacted, will provide the basis for a sound investment in the future of the nation and Illinois.

Thus, passage is needed of the Geologic Mapping Act of 1991, a bill that has been introduced in Congress to facilitate the production of the required detailed maps. The key element of the proposed program is the State Geologic Mapping Component, calling for matched state and federal funds, starting at $15 million and stepping up to $25 million per year in the fourth year. A multi-year effort, the program requires secure, dedicated funds. The House passed its version of the bill in late 1991. The Senate and Congress are expected to pass the legislation in the current session. Support of the appropriation is needed to implement the authorizing legislation.

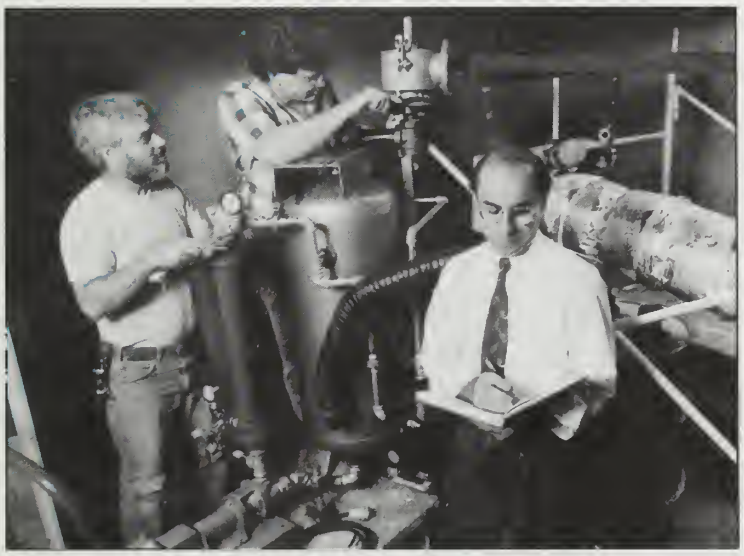
Parallel legislation at the state level is required to ensure proper coordination of the state and federal programs and to implement a prudent program to meet Illinois' needs in a timely way...to ensure that this state is in a position to participate and receive its share of federal funds. A federal appropriation at the $15 million level and growing to $25 million should provide between $700,000 to $1,100,000 per year in federal funds to Illinois for mapping. The addition of state matching funds may permit Illinois to be mapped at a scale of one inch equals 2,000 feet in about 25 to 35 years, depending on the level of funding. Thus, time can be reduced in half with federal-state matching funds and perhaps to 17 or 18 years with contributions from other beneficiaries such as local and county governments and industry in Illinois.

A state and federal program of geological mapping is in the national interest. Benefit/cost studies indicate that geologic maps will save the nation and state money. The proposed legislation, if enacted, will provide the basis for a sound investment in the future of the United States and Illinois.

Future Challenges Abound

Research investigations and service efforts of the ISGS address the state's issues or anticipated needs, taking trends into account. Such trends include a greater concern for the environment and quality of life. In fact, the Governor's office asked ENR to develop a program to assess the environment in Illinois. Based upon a report by the Science Advisory Board of the USEPA, the Geological Survey and the other scientific divisions of ENR evolved a plan to conduct and report on a critical trends assessment of environmental elements in the state.

This Critical Trends Assessment Project will use the extensive data base for Illinois and the computerized IGIS to advance the management of the state's environment and natural resources into the next century. Two goals are foremost: to develop an integrated environmental data base, merging economic, social and natural resource information for analyses by the IGIS; and produce a state-of-the-environment report for Illinois. The environmental trends which evolve from the analyses can be synthesized into a report written for the general public that will provide an overview of the state's environment and the implications for human health, economical health, and quality of life. More importantly, the report that results from the analyses will help assure that environmental policy is based upon a comprehensive picture of trends and rate of change. A more meaningful perspective should evolve as the Survey and the state work toward both a healthy economy and a healthy environment.



From the left, Jimmy Cooper, craftsman, Dave Moran, chemical engineer, and Massoud Rostam-Abadi, senior chemical engineer, prepare to operate the process optimization unit which will provide engineering data for the scale-up of the Geological Survey's process producing high-surface-area hydrated lime. This product will increase the effectiveness of dry-injection systems for decreasing sulfur-dioxide emissions, producing results, in pilot-scale tests, sufficient to bring Illinois' coals into compliance with the goals of acid rain legislation for the year 2001. A patent covering the process has been applied for.

Toward these goals, near-term challenges for the Geological Survey, as one of the state's earth agencies, include:

- **Transfer of the high-surface-area (HSA) hydrated lime process to industry**

Continued development of the HSA hydrated lime technology and transfer of its technology to the commercial market is required as rapidly as possible to increase the use of Illinois' coal by utilities, its major market, threatened by acid-rain-reduction goals that restrict sulfur emissions. This post-combustion cleaning process, developed by the ISGS' researchers, will increase the effectiveness of dry-injection systems for decreasing sulfur-dioxide emissions, having achieved superior sulfur-dioxide removal results over other hydrates tested (up to 90 percent increased effectiveness).

- **Maintaining the marketability of Illinois' coal resources**

Programs to decrease sulfur-dioxide emissions have been well established at the ISGS, including research to decrease the sulfur and mineral-matter content (precombustion cleaning), research to more economically remove sulfur dioxide from combustion gases such as the lime hydrate, and programs to encourage and aid researchers throughout the world to help solve problems associated with the use of Illinois' coal.

Through continued research, the ISGS looks forward to breakthroughs on liquids from coal by means of mild gasification; lignin-enhanced depolymerization of coal; and other projects needed to help maintain viable markets for Illinois' coal.

- **Stable state funding for oil recovery research**

Stable, long-term funding must be implemented to support the state's share of the promising state-federal cooperative research program on improved and enhanced oil recovery, highlighted in this report.

- **Stable state funding for the IGIS**

Stable, long-term funding must be developed to support the continued operation and maintenance of the IGIS and to support the continued development of the various computerized data bases required by its users.

- **Groundwater protection research program**

Continued research and enhanced financial support is needed to meet the mandates of the Illinois Groundwater Protection Act, especially projects directed toward developing an understanding of the present quality of groundwater, to establish a base line against which to compare any future changes in its quality, and to protect this vital resource.

- **Contributions of the ISGS to waste management programs**

Greater efforts are needed to gain recognition and use of geologic maps and the GIS in providing technical assistance for landfill-site screening as an integral part of programs in solid waste management and to recognize the continued need for siting some landfills. Even if programs for recycling and waste reduction are highly successful, some waste will always be generated.

- **Funding for a statewide geologic mapping program**

An initiative must be implemented for a fully-funded program to map the geology of Illinois in the detail required to respond to modern needs for geological information. Illinois' program should include a clear authorization for the expenditure of at least $1.1 million per year in 1990 dollars, with or without matching funds from federal or other sources.

Looking ahead three to five years, longer-term challenges to the ISGS include:

- **Rebuilding the infrastructure**

A program needs to be implemented to find and characterize the aggregate materials and other industrial and metallic mineral resources that will be required to rebuild the crumbling infrastructure. Such information can be a significant outgrowth of the geologic mapping initiative.

- **Environmentally responsible development and use of fossil fuels**

Research must be continued on the environmentally responsible development and use of fossil fuels to sustain the economy of southern Illinois. While alternative fuels, like ethanol and hydrogen, and alternative energy sources, like solar and wind power, will be an increasingly important part of the overall energy supply for the United States, coal and liquid hydrocarbons will continue to be major sources of energy for the foreseeable future. Because no other energy sources occur in such a convenient form and at such a low cost, they will continue to be the touchstones against which the economic viability of other energy sources will be measured.

- **Broad-based research program on global climate change**

A need exists to develop a broad-based, integrated, department-wide research program on global climate change and its potential impacts on the environment and the economy of Illinois. The program should not only examine observable changes in the climate and atmospheric composition, but it should also examine the manner in which activities of industries in the state affect the climate and atmosphere and whether proposed remedial actions will have an impact on the accumulation of greenhouse gases. The Department of Energy and Natural Resources is uniquely equipped to carry out the kind of full life-cycle analyses necessary to determine

whether a proposed energy conservation strategy or alternative fuel production method is neutral or beneficial in terms of reducing greenhouse-gas emissions. The potential impacts on Illinois' biological diversity and groundwater quality of altered agronomic practices for purposes of biomass fuel production (derived from fermenting wood or agricultural wastes) also require close examination.

- **Improved technology transfer program**

A program needs to be implemented to significantly enhance the ability of the ISGS to transfer its technologies and other scientific information to the people who need it.



Minerals engineer Hank Ehrlinger monitors the 12-foot-tall Deister flotation column at the Applied Lab. With column flotation, waste material from coal preparation plants is fed in slurry form into this type of column. A mixture of tiny air bubbles, chemical reagents and water is added. The fine coal particles adhere to the air bubbles and rise to the top of the column where they are removed as a concentrate. This method generates coal that contains more than 13,000 Btu per pound. The resulting coal slurry may be ideal for use in coal gasification because it is ready to be made into a gasifier feed slurry with little additional processing.

In addition to fundamental improvements in the Survey's abilities to provide computer access to major data files, staff, equipment and space are required to allow more frequent workshops, seminars and other free forums as a means of conveying the Geological Survey's data and research information to the public.

- **Public education on the importance of independent scientific research for environmental and mineral resource issues**

The Survey must speak for the importance of maintaining a strong, politically independent, non-regulatory scientific research arm, capable of providing state and local governmental officials with unbiased scientific analysis of the increasingly complex environmental and mineral resource issues confronting Illinois.

Illinois faces serious issues concerning its water, land, energy and mineral resources. Can it ensure an adequate supply of these resources? Are these resources being properly used? Are other uses possible that would help stimulate the economy? Are there new emerging technologies that will help in striving toward economic and environmental health?

Environmental issues related to the management and protection of Illinois' resources abound—issues that involve public safety, health and recreation; agriculture; and the state's infrastructure. Is groundwater contamination a problem? If so, where? How do we protect our groundwater? How should we manage wastes to avoid contamination? How do we produce clean coal? Can natural or man-caused hazards be prevented or mitigated? Can we use Earth's processes and resources to our advantage to improve conditions and enhance the quality of life?

Responses to these and similar questions depend on continually increasing knowledge and understanding of our surroundings—of the structure, resources and dynamics of the Earth—the **detailed** geology of this state. The public and governmental officials require this type of scientific information to make informed decisions about the wise use of the finite and precious resources—decisions which will affect the standard of living, economic growth health and safety of Illinois' residents and can have an impact on the nation as well. To this end, the ISGS is mandated to provide the geologic knowledge and information to help answer such questions.

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